14.1: Detection Methods

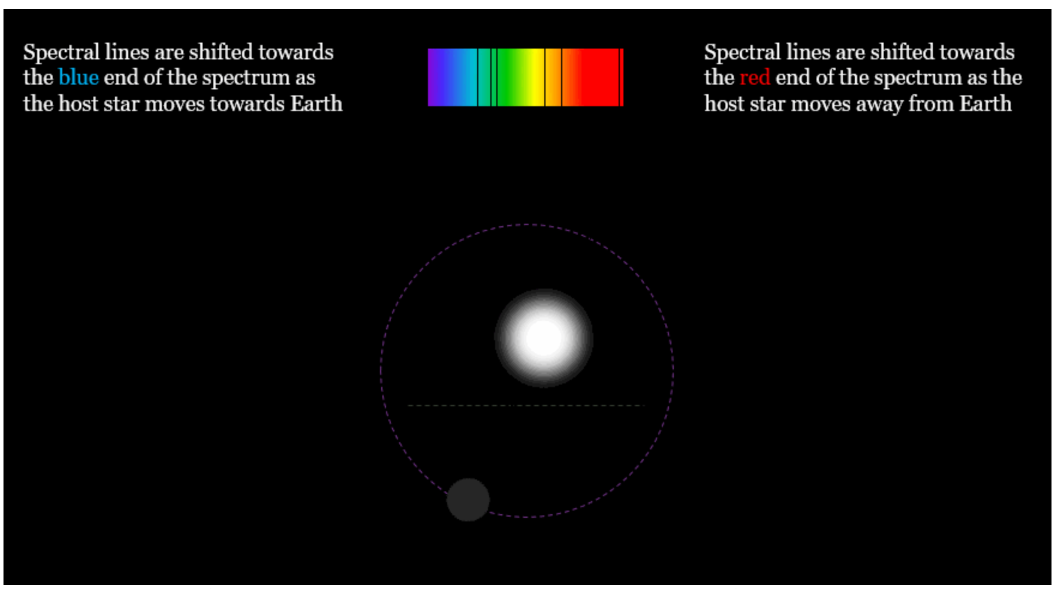
14.1.1 Doppler and Transit Methods

Searches for exoplanets fall into two categories. In **direct** methods, astronomers find images or spectra of the planets themselves. In contrast, **indirect** involve making measurements of stellar properties revealing the effects of orbiting planets on the motion of parent star.

The first successful methods in exoplanet detection involved looking for signs of the planets exerting gravitational tugs on their host stars. A Newton demonstrated, planets and their host stars orbit around their common center of mass. Because stars are much more massive than planets, a star will only make a tiny "wobble" around the center of mass while the planets make large orbits. The more massive the planet, the larger the stellar wobble. For example, as the Sun and Jupiter orbit around their common center of mass, the Sun wobbles around that center of mass with same period as Jupiter. Since the Jupiter is the most massive planet in our solar system, it exerts the largest wobble on the Sun of the planets. The Sun's total motion around the solar system's center of mass depends on tugs from all the planets. Looking at the solar system from a great distance, however, the motion caused by the orbit of Jupiter would be most detectable.

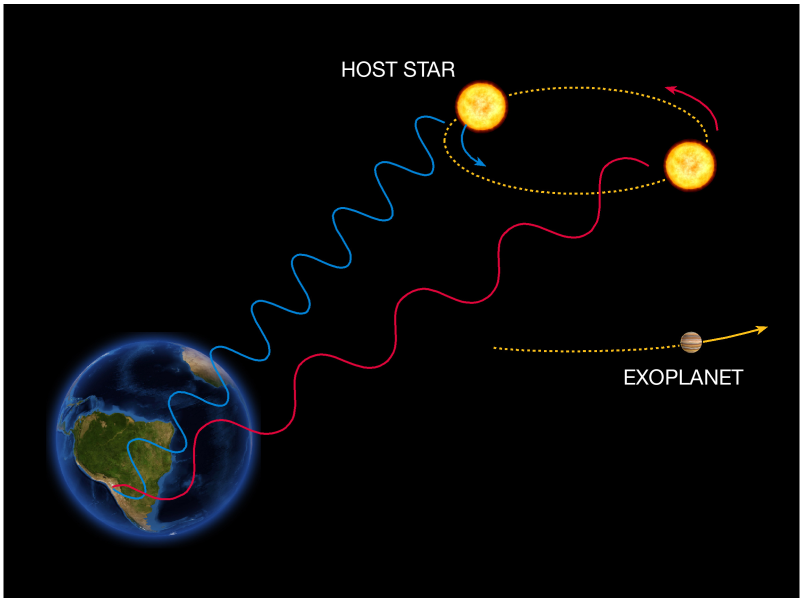
Astronomers looking at other stars searched for means to measure this motion to both infer the existence of exoplanets as well as determine their masses and orbit. One technique to detect this motion is the astrometric technique, which we detect exoplanets by measuring the change in a star's position on sky. However, these tiny motions are very difficult to measure (~ 0.001 arcsecond). As a result, few exoplanets have been detected using the astrometric technique. Date from the GAIA spacecraft as it makes precise measurements of the location and motion of the stars in our galaxy may help. There is hope that astrometric techniques can find more exoplanets in the future.

Meanwhile, numerous exoplanets, including 51 Pegasi b, have been found using the Doppler technique. This involves measuring a star's Doppler shift can tell us its motion toward and away from us. As the star wobbles around the center of mass of the system, it will alternatively move toward the Earth and away from the Earth in regular intervals. This will cause periodic red and blue shifts in the star's light output. Current techniques can measure motions as small as 1 m/s (walking speed!).



The Doppler shift can be used to detect an exoplanet based on its influence on the star's motion.

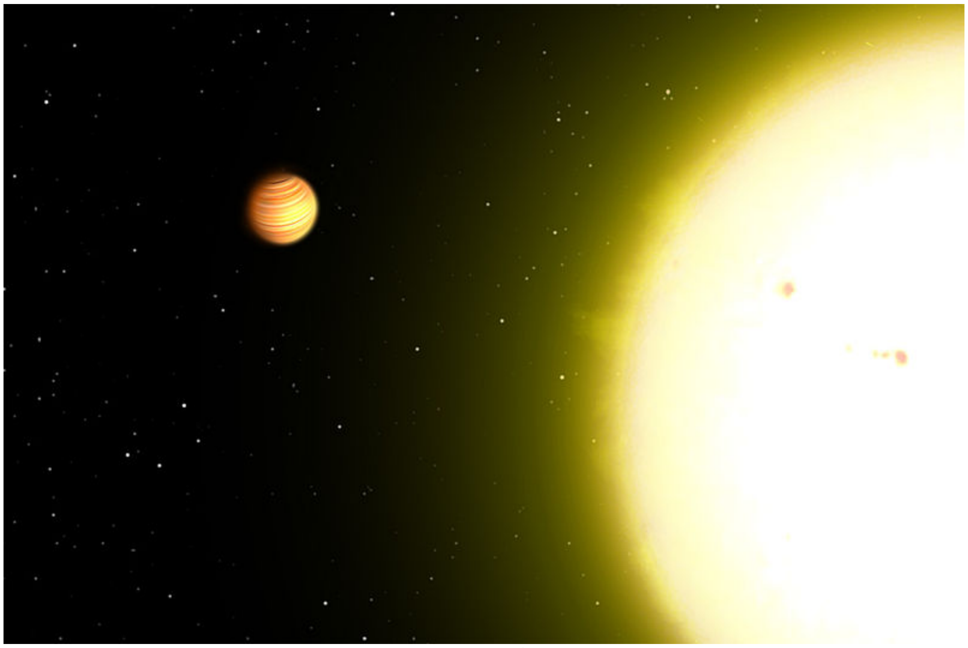
https://commons.wikimedia.org/wiki/F..._exoplanet.gif



The Doppler Method.

https:/commons.wikimedia.org/wiki/File:The_radial_velocity_method_(artist%E2%80%99s_impression).jpg;

Doppler shifts of the star 51 Pegasi indirectly revealed a planet with 4-day orbital period. Such a short period means that the planet has a small orbital distance. Calculations determined that 51 Pegasi b has a mass like Jupiter's, despite its small orbital distance. Its large mass and closeness to it host star led astronomers to coin the phrase “Hot Jupiter” to describe this class of exoplanet.

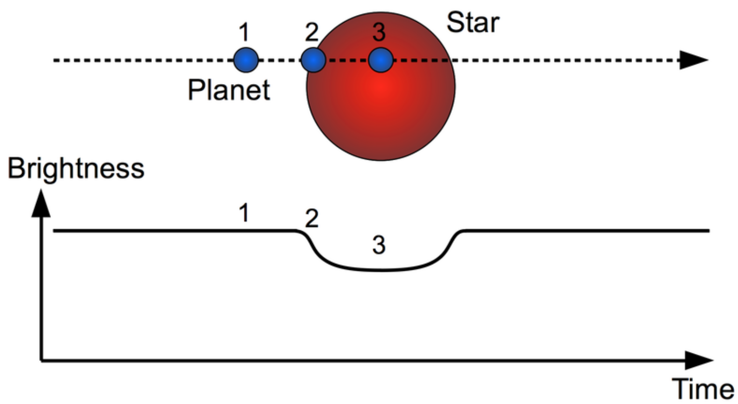

Artist's conception of 51 Pegasi b.

https:/commons.wikimedia.org/wiki/File:51_Pegasi_b_v1.jpg;

Since the discovery of the 51 Pegasi b, astronomers have found numerous other hot Jupiters. Because of their large masses and short orbital periods, hot Jupiters produce Doppler shifts that are relatively easy to detect. Their short orbital periods also mean we do not need to sift through years of data to find the patterns of shifts. For these reasons, nearly all of the early exoplanets discovered fall into the category of hot Jupiters.

Date from Doppler shift can tell us about a planet's mass and the shape of its orbit. However, we cannot measure an exact mass for a planet without knowing the tilt of its orbit, because Doppler shift tells us only the velocity toward or away from us. It gives us no information about any lateral (left to right) motion resulting from the exoplanet's orbit. As a result, Doppler data only give us lower limits on masses.

Other exoplanets have been found using the brightness or transit technique. This involves the periodic dimming of the parent star's brightness. A **transit** is when a planet crosses in front of a star. Whenever a planet transit, it produces a dip in the star's brightness. An **eclipse**, when the planet passes behind the star, can also be sometimes observed. The changes in brightness from transits and eclipses are very minute and require precise and care measures.



The transit method can be used to detect an exoplanet by the periodic dimming of a star.

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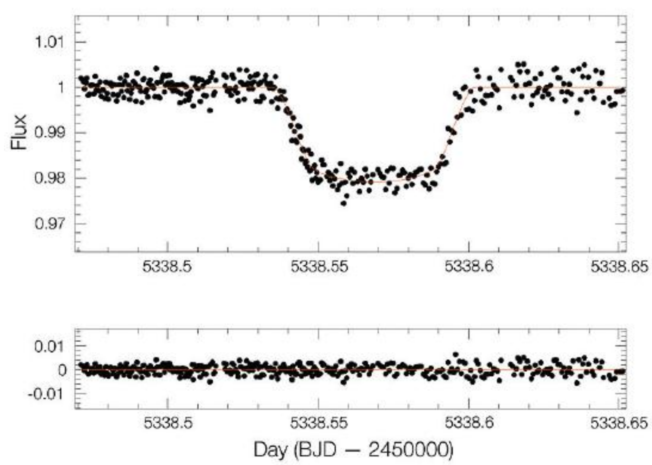


This data curve shows the dimming of light from a star.

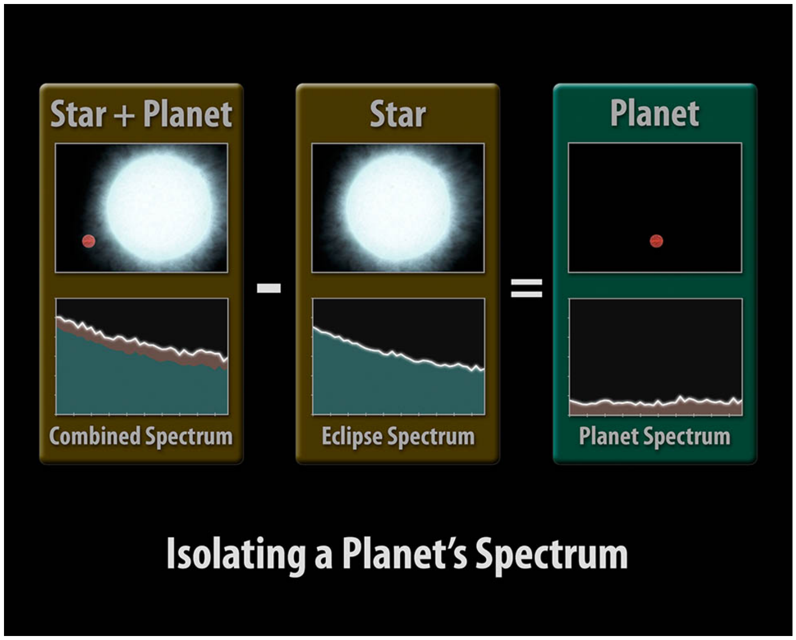
https://commons.wikimedia.org/wiki/F...t_WASP-19b.jpg)

As astronomers look for periodic changes in brightness, they can divide the planet's motion into six phases.

1. Before transit when the star is at full visible light brightness.
2. Transit begins and a noticeable drop in brightness begins.
3. During transit, the planet blocks a small percentage of the star's visible light.
4. Before eclipse, at this point, the planet emits infrared radiation, and the total infrared spectrum includes that of both the star and the planet.
5. Eclipse begins, and the infrared spectrum dips as the planet's infrared radiation is blocked by the star.
6. During eclipse when the planet's infrared spectrum is blocked until the planet emerges on the other side the star.

By measuring the time it takes for the electromagnetic spectrum to go through the cycle of both visible and infrared dimming, astronomers can determine the exoplanet's orbital period. In addition, the amount of dimming that occurs as transit begins enable astronomers to infer the size of the planet. Also, the planet's atmosphere may dim additional light and produce an absorption spectrum, enabling astronomers to identify the composition of the atmosphere. Finally, measuring changes in the infrared spectrum during eclipse enable scientist to infer the planet's temperature.

Unlike the Doppler technique, the brightness technique is not limited by orbital tilt, enabling more accurate measurement of planet mass.



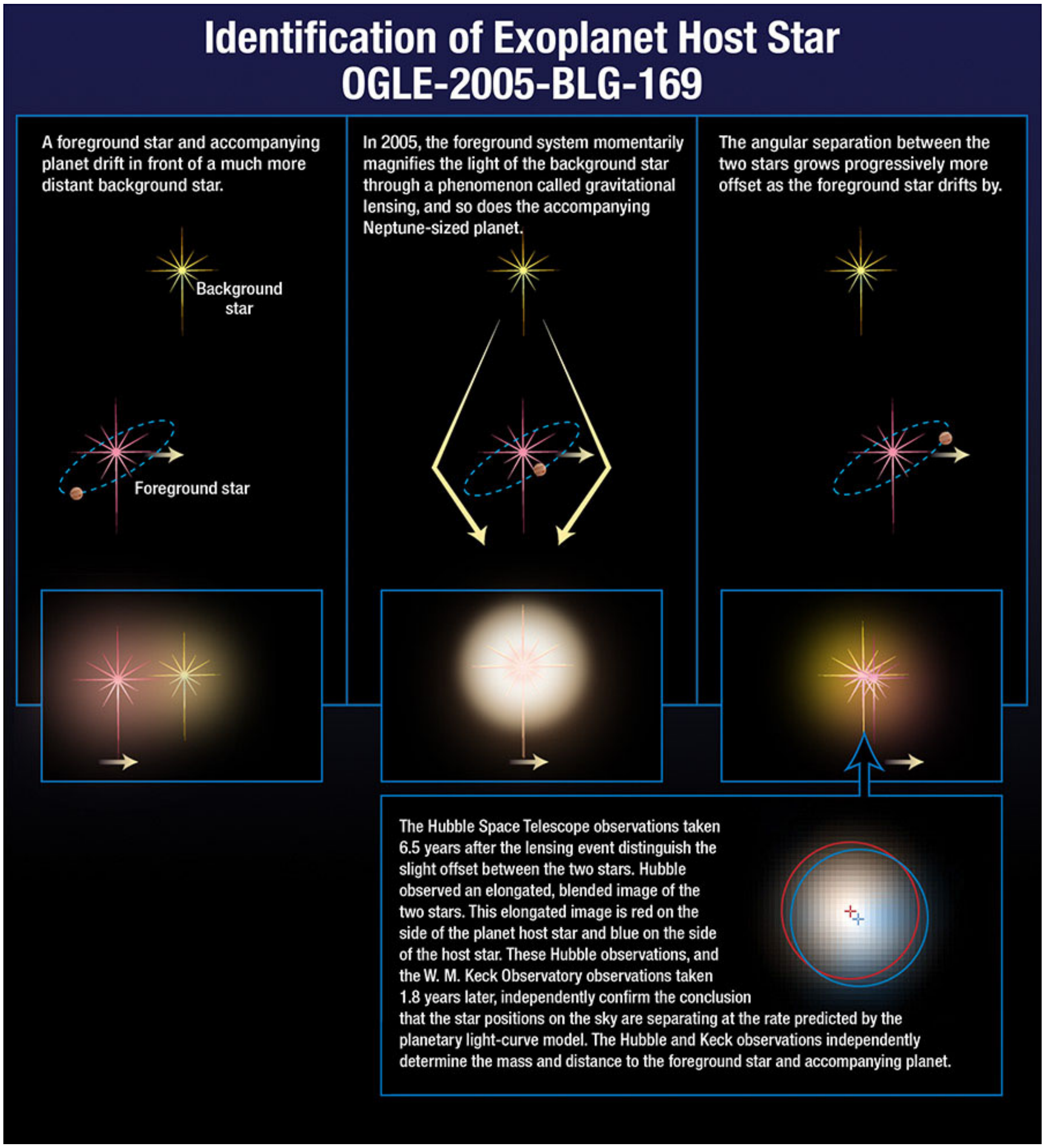
Isolating a planet's spectrum.

https:/exoplanets.nasa.gov/resources/58/isolating-a-planets-spectrum;

The Kepler Mission used the brightness technique to find thousands of planet candidates. Launched in 2008 it began looking for transiting planets. Unlike the Hubble Space Telescope, which can be pointed into almost any direction, Keppler remained focused on a single region of space during its initial mission. During this time, it gathered date from thousands of stars. Keppler was designed to measure a 0.008% decline in brightness when an Earth-mass planet eclipses a Sun-like star.

14.1.2 Gravitational Microlensing

Other techniques include **gravitational lensing.** Einstein's theory of general relativity states that gravity is the result of the warping of spacetime due to the mass of a large object. A electromagnetic waves pass through the warped spacetime, its path bends in response. The gravitational lensing method depends on how mass bends light when a star with planets passes in front of another star. Because it requires two stars to line in one behind the other at just the right time, gravitational lensing is a more difficult method. Scientists must find a star at just the right moment to spot the lensing effect.



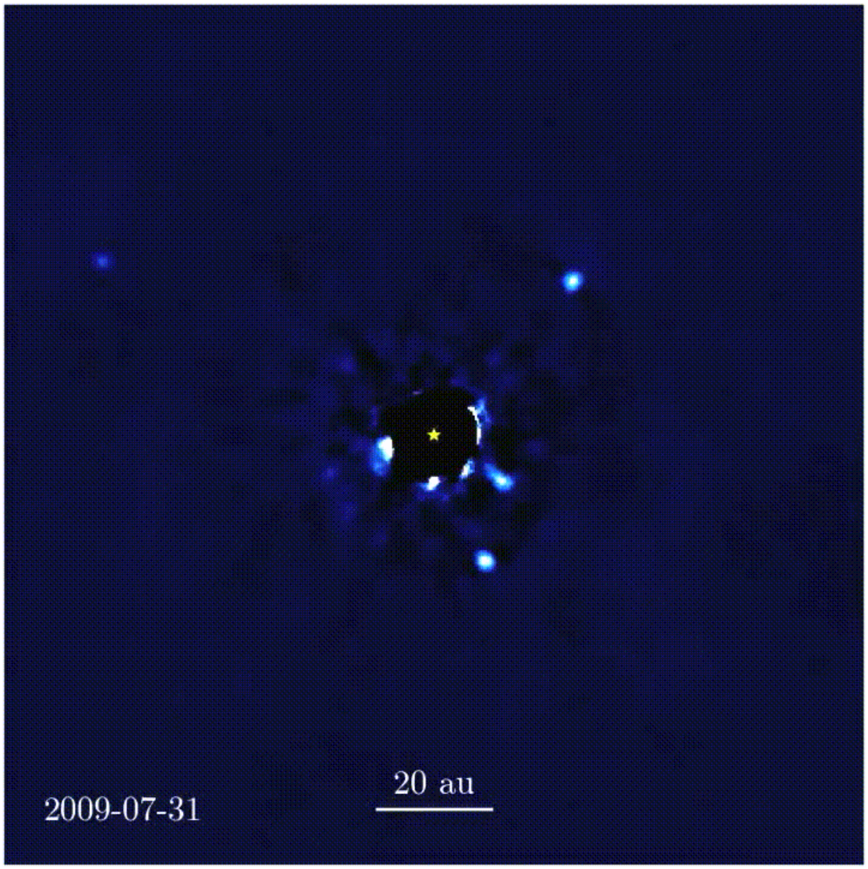
Gravitational microlensing can be used to detect exoplanets.

https://exoplanets.nasa.gov/resource...-2005-blg-169/

Astronomers can also find the presence of exoplanets by looking at gaps, waves, or ripples in disks of dusty and gas around newly forming stars.

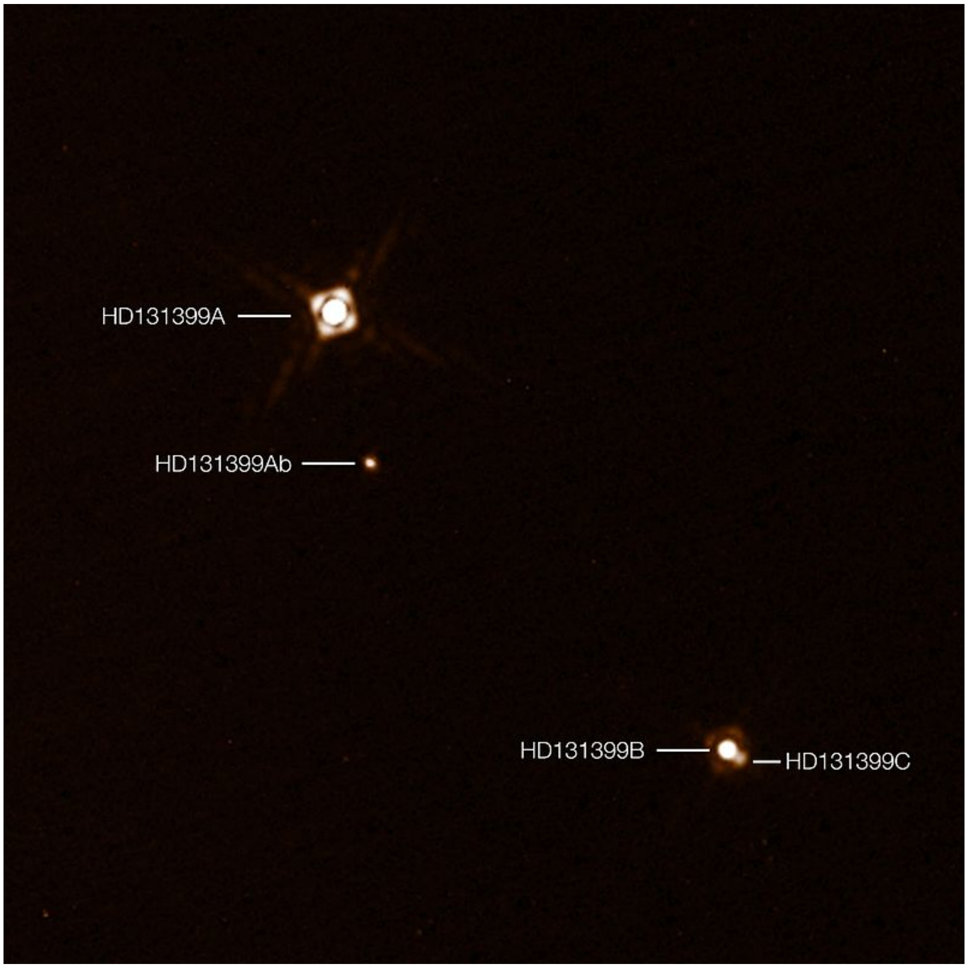
14.1.2 Direct Imaging

Most recently, advances in image resolution through adaptive optics have enabled us to make **direct detection** of exoplanets possible. Unlike other methods, which only detect the affects exoplanets have on brightness or motion of stars, direct detection enables us to image the exoplanets directly. Direct detection. Techniques using coronagraphs to block the bright light from stars can also aid in detecting planets around them. Once the James Webb Space Telescope is launched, data collected from it will help astronomers perform more direct detection of exoplanets.



Direct imaging of exoplanets.

https://en.wikipedia.org/wiki/File:H...Exoplanets.gif



Direct image of orbiting exoplanets.

https:/commons.wikimedia.org/wiki/File:Eso1624d.jpg;